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**EVALUATION OF A TRANSPORTABLE HOT-GAS DECONTAMINATION
SYSTEM FOR THE DECONTAMINATION OF EXPLOSIVES-CONTAMINATED
DEBRIS AND PIPING**

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INTRODUCTION

The manufacture, handling, and loading of explosives at Army industrial facilities have resulted in the contamination of process equipment such as piping, pumps, motors, powder boxes, and sewer systems. Because of this residual contamination, process equipment, piping and sewer lines cannot be reused or disposed as scrap without some sort of remedial treatment.

Over the years, the U.S. Army Environmental Center (USAEC) has investigated technologies that could be used effectively to treat explosives-contaminated materials. Using process equipment supplied by the government, pilot studies conducted at Hawthorne Army Ammunition Plant have shown that decontamination of explosives-contaminated structural components is possible. The process used a heated gas to thermally decompose or volatilize explosives with subsequent incineration in an afterburner.

Based on engineering data gathered during the Hawthorne pilot studies, WESTON, under contract to the United States Army Environmental Center (USAEC), was requested to design and supply a hot-gas decontamination system which is transportable and easily procured through commercial sources. The finished equipment was delivered to the Alabama Army Ammunition Plant (ALAAP) to conduct an equipment shakedown and validation testing using explosives-contaminated piping and oversized debris. The purpose of validation testing was to verify the effectiveness of the hot-gas process to remediate explosives-contaminated piping and debris to levels which would allow this material to be disposed of as scrap and to maintain at least a 99.99% destruction and removal efficiency (DRE) of contaminants out of the system afterburner. A total of nineteen (19) test runs were conducted during the validation testing period.

Testing activities conducted at the ALAAP with the hot-gas system, have demonstrated that the hot-gas technology can be used to support ongoing base decontamination operations and base closure activities where explosives contaminated piping, process equipment, and/or debris pose disposal nightmares.

BACKGROUND

The Department of Defense (DOD) owns a large inventory of materials that are contaminated with energetic compounds of explosives, propellants, or pyrotechnics, as a result of depot activities, ammunition plant manufacturing processes, and munitions demilitarization activities. As a matter of good management practice, these materials are routinely decontaminated using commonly used decontamination methods such as steam cleaning and fire.

Although steam cleaning effectively decontaminates the surfaces of contaminated materials to a 3X condition, contaminants may still be present in the surface voids or equipment internals. The 3X process also produces contaminated wastewater which must be treated before reuse or discharge. At present, there is no analytic method available which accurately determines the contaminant concentration left within the pores of materials which have been decontaminated to meet 3X criteria, however, in order for these materials to be released from government control to be landfilled, scraped, or reused the materials must meet 5X criteria.

By definition, 5X treatment assumes materials are thermally heated to a uniform temperature of 1,000°F for a minimum of 15 minutes. Fire is the most effective means currently used to decontaminate explosives- and energetic-contaminated materials to the 5X condition. In some instances this process is controlled by flashing contaminated materials within an enclosed oven, but more commonly the process is uncontrolled

and accomplished by open air burning and/or detonation. Since environmental regulations are becoming more rigorous every year, it's likely the practice of open burning and/or open detonation for decontamination of explosives-contaminated materials will be severely limited or disallowed because this process results in non-regulated air emissions. The flash ovens allows control of process off-gases, however, the process is essentially an incineration process which currently carries both negative public and regulatory agency perceptions. Finally, materials decontaminated using either open burning or flashing methods are usually not suitable for reuse and must be scrapped or landfilled.

Is there an alternative? Is there a process that not only successfully decontaminates explosives- and energetic-contaminated materials, but a process that achieves decontamination levels equal to 5X criteria? Is there a process whose emission levels can be monitored throughout the decontamination process? Is there an available process which has none of the negative connotations of incineration, but is still able to successfully decontaminate equipment so that the equipment could be reused following decontamination? USAEC's testing with the hot-gas process seems to meet these requirements.

Hot-Gas Decontamination (HGD) Technology History

USAEC has been conducting laboratory investigations and pilot-scale studies of the hot-gas process since 1978. Based on promising laboratory work with chemical warfare agents, a pilot-scale study using agent spiked samples was conducted at Dugway Proving Ground, Utah¹. This controlled pilot-scale study successfully demonstrated the ability of the hot-gas process to decontaminate agent from a concrete and steel structure.

To further evaluate the hot-gas process on agent, USAEC selected a mustard thaw pit at the Rocky Mountain Arsenal for a field demonstration of the hot-gas process². Three tanks (2-2,600 gallon and 1-250 gallon) were also left in the mustard pit during the field demonstration to test the effectiveness of the hot-gas process in decontaminating process equipment. This field demonstration once again proved the effectiveness of the hot-gas process. Mustard agent was successfully decontaminated from the concrete pit, contaminated steel tanks, and process off-gases.

Based on the successful pilot-study results at Dugway, USAEC determined to investigate the effectiveness of the hot-gas process on explosives-contaminated materials. Pilot-scale tests of the hot-gas process, using explosives-contamination, were conducted at the Cornhusker Army Ammunition Plant³. Results from the Cornhusker tests indicated that the hot-gas process seemed to be effective at treating explosives-contaminated materials. To verify this finding, USAEC contracted for additional hot-gas studies to be conducted at the Hawthorne Army Ammunition Plant^{4,5} using a flash chamber modified for the hot-gas process. Explosives-contaminated machinery, piping and metal debris such as shell casings were treated in one study, and explosives contained within munitions such as ship mines, depth bombs, and 106mm - 5 inch

¹ Pilot Plant Testing of Hot-Gas Building Decontamination Process; Task Order 1. Report No. AMXTH-TE-CR-87130. Prepared by Batelle Columbus Division. 30 October 1987.

² Final Technical Report, Field Demonstration of the Hot-Gas Decontamination System. Report No. SFIM-AEC-ET-CR-95011. Prepared by Batelle Pacific Northwest Laboratories, Parsons Engineering Science, Inc., and Batelle Columbus Operations. February 1995.

³ Pilot Plant Testing of Caustic Spray Hot-Gas Building Decontamination Process; Task Order 5. Report No. AMXTH-TE-CR-87112. Prepared by Arthur D. Little, Inc. August 1987.

⁴ Task Order - 2: Pilot Test of Hot Gas Decontamination of Explosives-Contaminated Equipment at Hawthorne Army Ammunition Plant (HWAAP) Hawthorne, Nevada. Report No. CETHA-TE-CR-90036. July 1990. Prepared by Roy F. Weston, Inc. July 1990.

⁵ Demonstration Results of Hot Gas Decontamination For Explosives at Hawthorne Army Depot. Report No. SFIM-AEC-ET-CR-95031. Prepared by The Tennessee Valley Authority Environmental Research Center. September 1995.

projectiles were treated in a second series of tests. The results from these studies verified the effectiveness of the hot-gas process in treating explosives-contaminated materials, but indicated that equipment enhancements would be required to optimize the process.

Hot-Gas Decontamination System Equipment Design Criteria

At both Cornhusker and Hawthorne, modified equipment proved the basic validity of the treatment process, but post test recommendations indicated that better system efficiencies and process optimization could be achieved using equipment specifically designed for the hot-gas decontamination concept.

Starting with these recommendations as a baseline, USAEC contracted WESTON to design and procure hot-gas decontamination system equipment which could meet the following equipment criteria:

- Design a system which could be procured easily from commercial sources. "Custom" equipment designs were discouraged.
- Size the equipment so that it could be transported easily from site-to-site.
- Design a system which could be operated either locally at the equipment or remotely from a control room to ensure operator safety.
- Design process equipment which minimized system leakage.
- Provide system equipment which could reach treatment temperatures quickly and maintain treatment temperatures once operations began.

The Selected Hot-Gas Decontamination System Design

Based on the noted design criteria, the general arrangement for the second generation hot-gas equipment design which was supplied to USAEC is shown in Figure 1. The hot-gas equipment which was delivered to USAEC's Alabama Army Ammunition Plant (ALAAP) hot-gas site is a skid-mounted, easily transportable unit which consists of four basic elements: the hot-gas furnace, the system ID Fan, the afterburner, and stack. The hot-gas equipment furnished operates on a batch basis and is controlled remotely from two (2) remote control panels. The unit can also be operated locally to support system maintenance activities.

The hot-gas furnace was supplied by L&L Special Furnace Co., Inc. of Aston, PA. The furnace is a propane-fired, box-type furnace with an integrated ceramic fiber-lining. The furnace is rated for a total heat release of 1 million Btu per hour. Depending on the load size and material composition of the load, the furnace can easily maintain material temperatures up to 700°F. The furnace skid is approximately 17 feet long by 7 feet wide.

The system Induced Draft (ID) Fan is mounted downstream of the furnace on the afterburner skid and is used to maintain a negative draft between the furnace and afterburner. The fan was furnished by Chicago Blower, supplied with a variable speed drive, and rated for 2,250 cfm at 650°F. The fan has also been

equipped with vibration sensors and over-temperature sensors to alarm when furnace off-gases reach temperatures in excess of 700°F.

The afterburner equipment and stack were furnished by Arrtech Environmental Systems, Inc. of Tulsa, Oklahoma. The afterburner is propane-fired and rated for a total heat release of 2.45 million Btu per hour.

The afterburner is capable of thermally treating approximately 3,400 LB/hr of contaminated off-gases from the hot-gas furnace at a treatment temperature of 1,800°F with a minimum residence time of 2 seconds. The afterburner skid is approximately 28 feet long by 6 feet wide. The system stack, which is located at the discharge end of the afterburner, is approximately 23 feet high with a 29 inch inside diameter. The stack is equipped with 8 sample port locations to support emissions testing. The stack is disassembled from the skid and laid on its side to support shipment.

The afterburner and furnace systems were each supplied with a local and remote control panel. The local panels are located on each respective skids. The remote control panels for each system were located approximately 750 feet away from the hot-gas equipment, in a control room trailer. All system equipment can be started and stopped from either the local or remote panels. Both furnace and afterburner systems are equipped with individual temperature and burner controls. System interlocks, which create interdependency between the systems, have been installed to prevent startup or continued operation of the equipment when either a safety or operational condition exists which would require system shutdown.

Because of the small system footprint and height of the system, the hot-gas equipment can be easily transported over the road. It is unlikely that special permitting would be required to ship the system. Skid mounting allows for "pick and place" setup of the equipment once a suitable area has been prepared. We suggest allowing 2 days for equipment placement. For testing at ALAAP, the hot-gas equipment was placed on a curbed, concrete pad. The site was supplied with 480-volt electrical service, and a 5,000 gallon capacity propane tank to supply system propane. No system water is required.

Purpose and Objective of Validation Testing at Alabama (ALAAP)

Although pilot-scale studies have shown the hot-gas decontamination process to be effective in treating explosives- and agent-contaminated materials, potential users still have questions about the technology. Of primary concern:

- What are the costs associated with a full scale application
- Will the technology work on "my" specific explosives-contamination profile without creating other environmental hazards?

To address these concerns, USAEC contracted WESTON to conduct validation tests of the hot-gas equipment illustrated by Figure 1. The objectives of the hot-gas process validation tests were to evaluate the operability of the equipment and to determine:

- The effectiveness of the hot-gas process on various explosive-contaminated items such as: metal, clay pipe, and contaminated debris.
- The destruction and removal efficiency (DRE) of the hot-gas process using clean metal, clay pipe, and debris (cinder block) spiked with 2,4,6-trinitrotoluene (TNT), cyclotrimethylenetrinitramine (RDX) and 2,4,6-trinitrophenylmethylnitramine (Tetryl).

- The time and temperature relationships for the decontamination of explosives on metal, clay and block surfaces.
- The optimum treatment time and temperature required for the complete destruction and removal of explosives and their breakdown components .
- Gather air emissions data on the hot-gas process to support future permitting of the process and equipment.

To meet these objectives a test plan was developed ⁶. The test plan was reviewed and approved by USAEC. Permission to conduct testing was also required from the Alabama Department of Environmental Management (ADEM).

TEST PLAN and TREATMENT CRITERIA

To meet the test objectives a total of 15 validation test runs, as illustrated by the test matrix provided in Table 1, were planned . Treatment temperatures ranged from 300°F to 650°F depending on the test run. A combination of clean metal pipe, clean clay pipe, and clean cinder block were spiked with an explosives-paste mixture which contained either TNT, RDX, or Teteryl. Twelve of the 15 test runs , as indicated by the (D) on the matrix, also treated contaminated debris from the ALAAP remediation effort. A spike mixture contained only explosives-type and was not mixed with other explosives-spike mixtures on the same test plate. Once the hot-gas furnace reached the desired treatment temperature, soak times (or hold time) were varied from 0 - 12 hours soak time depending on the test run.

TABLE 1
VALIDATION TEST MATRIX

| Temperature | 300°F | 400°F | 500°F | 550°F | 600°F |
|--------------|----------|-------------|-------------|----------|--------------------------------|
| No Soak | | | | | Test #9, #16A, 16B, #16C |
| 1 hour Soak | Test #12 | Test #11 | Test #13 | Test #10 | Test #7, #14, #15 |
| 2 hour Soak | | | Test #8 | | Test #6 |
| 4 hour Soak | | | Test #3 (E) | | Test #5 |
| 6 hour Soak | | Test #2 (E) | Test #4 | | |
| 12 hour Soak | | | Test #1 (E) | | |

(E) Indicates furnace discharge gas and emissions testing was conducted during these test runs.

Confirmatory sampling and analysis was conducted before and after treatment using EPA Methods SW8460 and 8330. The 8330 analysis uses an HPLC to analyze for the 9 explosives and explosives-breakdown components listed below.

⁶ Draft Treatability Study Test Plan for the Evaluation of a Transportable Hot-Gas Decontamination System for the Decontamination of Explosives-Contaminated Piping and Debris. Revision 2. Prepared by Roy F. Weston, Inc. January 1996.

- Octahydro-1,3,5,7 tetranitro-1,3,5,7-tetrazocine (HMX)
- Hexahydro-1,3,5-trinitro-s-triazine (RDX)
- 1,3,5-Trinitrobenzene (1,3,5-TNB)
- 1,3-Dinitrobenzene (1,3-DNB)
- Nitrobenzene (NB)
- 2,4,6-Trinitrophenylmethylnitramine (Tetryl)
- 2,4,6-Trinitrotoluene (2,4,6-TNT)
- 2,6-Dinitrotoluene (2,6-DNT)
- 2,4-Dinitrotoluene (2,4-DNT)

Following treatment, wipe samples were taken from all spiked test plates. Clay and block test plates were then ground into a powder and analyzed for explosives residuals. The contaminated debris from the ALAAP remediation was wipe sampled before treatment to verify contamination levels. A combination of wipe and ground samples were taken after treatment to verify that no explosives residuals remained on the contaminated debris or test plates

To support validation testing, a rigorous emissions testing program was conducted during the first three validation test runs to support future permitting efforts of the hot-gas process by USAEC and to determine the system and afterburner destruction and removal efficiencies (DRE's). Hot-gas stack emissions were sampled for:

- Carbon Monoxide
- Carbon Dioxide
- Oxygen
- Total Hydrocarbons (stack and interconnecting duct)
- Nitrous Oxides (stack and interconnecting duct)
- Sulfur Dioxide
- Particulate
- Explosives
- Volatile and Semi-volatile Organics
- Metals
- Hexavalent Chromium
- Hydrochloric Acid and Chlorine Gas
- Dioxins and Furans

The stack team also took an explosives sample at the interconnecting duct between the furnace exit and afterburner inlet to support DRE calculations.

Stack emissions were monitored during all test runs by a Continuous Emissions Monitoring (CEM) system for the following constituents: carbon dioxide (CO₂), carbon monoxide (CO), total hydrocarbons (THC), oxides of nitrogen (NO_x), sulfur dioxide (SO₂), and oxygen (O₂). To gather

information regarding the furnace off-gas flow during decontamination activities, a THC and NO_x sample probe were placed in the interconnecting duct between the furnace exit and afterburner entrance.

Spiking, Furnace Loading and Operations

For each of the 15 test loads the furnace was charged with a combination of clean steel pipe, clean clay pipe, and clean cinder block. For test runs #4 through #15, contaminated debris from the ALAAP remediation was also loaded into the furnace. The contaminated debris had been pressure washed to meet 3X criteria and consisted of concrete chunks, rocks, old valves, and pieces of metal and clay piping. Because of permitting limitations, no more than 800 pounds of pre-contaminated material could be placed in any batch run. Because of equipment design limits, no more than 3,000 pounds total was loaded into the furnace for per batch run.

To support DRE calculations and evaluate the effectiveness of the hot-gas process, each test load contained 3 steel test plates, 3 clay test plates, and 3 concrete block test samples. These test plates and samples were spiked with either TNT, RDX, or Tetryl and placed throughout the test load within the furnace. Five furnace wall plates: 2 test plates on each side wall and 1 on the furnace door, were also spiked during each test run. Each of the 5 furnace plates were spiked with the same spike mixture within a test run, but alternated between TNT, Tetryl, and RDX between test runs. For instance, furnace test plates were spiked with: TNT for Test #1, RDX for Test #2, Tetryl for Test #3, TNT for Test #4, etc. Spike mixtures were made by combining the pure explosive (TNT, RDX or Tetryl) with enough acetone to form a paste-like consistency. Each test plate or sample was spiked with approximately 15-20 grams of a single spike mixture. Although TNT, RDX and Tetryl test plates were treated in each test run, spike mixtures were not mixed together on the same test specimen.

Once charged, the furnace door is secured and the decontamination process can be started. From start to finish a complete hot-gas test run consists of the following tasks:

- Spiking test plates and samples, if applicable
- Loading the furnace
- Afterburner start-up time necessary to reach 1,800°F.
- Furnace ramp-up time
- Material soak time, if used
- Burner shutdown
- Material cool-down time
- Post test sampling, if applicable.

Total test time will vary depending on the selected ramp-up rate to treatment temperature and soak times. For a series of 19 batch runs (15 validation tests plus 4 confirmation runs) conducted by WESTON, total treatment times varied from 13 hours for Test #1 to approximately 4 hours for Tests #16A - #16C which were conducted with no soak times. Since both the furnace and afterburner are lined with a ceramic-fiber insulation heat-up rates of 30-60 minutes were possible. Ramp-up rates to treatment temperature, treatment temperatures, and soak times at treatment temperature were varied. Ramp-up times varied from 50°F/hr during the first three validation test runs to 300°F/hr for some of the final test runs. As illustrated in Table 1, treatment temperatures varied between 300°F and 600°F and soak times varied between 0-12 hours. The conclusions drawn from these variations in ramp-up

times, treatment temperatures and soak times will be discussed in more detail in "Discussion of Results" section of this paper.

DISCUSSION OF RESULTS

After each test run test plates were sampled and analyzed for residual explosives-concentrations. In analyzing the results, WESTON established three levels of acceptance criteria to determine the effectiveness of the HGD process.

Acceptance Level 1: To pass this acceptance criteria post-treatment analysis must indicate 99.9999% or better removal efficiency of the spike explosives. Residual levels of explosives or explosives-breakdown compounds would not necessarily fail this criteria.

Acceptance Level 2: To pass this acceptance criteria post-treatment results must indicate the removal of all spike explosives compounds. The presence of TNT, RDX or Teteryl residuals would fail a test plate or sample. Removal efficiency was not considered.

NOTE: A sample which passed Level 1 criteria could fail this level due to trace levels of the spike explosives.

Acceptance Level 3: To pass this acceptance level the post-treatment sample must be completely free of explosives or explosives-breakdown compounds.

This was the toughest criteria to meet. Specimens which pass Level 1 and 2 criteria could fail this acceptance level due to trace levels of explosives-breakdown compounds, such as 1,3 DNT, regardless of detection level.

Discussion of Level 3 Results:

Table 2 provides a test matrix indicating the results of the validation tests using the most stringent acceptance level, Level 3. The dark, shaded blocks indicate failure or the presence of explosives or explosives-breakdown compounds regardless of detection level. Depending on the test conditions detection limits were as high as 18,000 μ g and low as 0.5 μ g.

Using the level 3 acceptance criteria, the data included on Table 2 indicates that explosives-contaminated materials can be decontaminated (no traces of explosives or explosives-breakdown compounds) at treatment temperatures of 600°F and 1-hour soak (Test #7, #14, #15). In tests #7, #14, #15, all traces of explosives were successfully decontaminated from the spiked test plates and samples. Tests #7 and #14 also successfully decontaminated the pre-contaminated debris. Test #15, failed due to traces of 1,3,5-TNB and 2,4,6-TNT (0.5 μ g and 0.7g, respectively). Although this level of contaminants is clearly non-reactive, they may not be low enough to pass a local treatment criteria.

In contrast, tests which were conducted at 600°F and no soak time (#9, #16A, #16B, and #16C) were only partially successful. Although test #9 failed contaminated debris for trace levels of 1,3,5-TNB and 2,4,6-

Table 2: LEVEL 3 ACCEPTANCE CRITERIA

| | 300°F | 400°F | 500°F | 550°F | 600°F | 600°F | 600°F | 600°F | 600°F |
|------------|-------|-------|-------|-------|-----------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------|
| No Soak | | | | | Test #9: 6hr 15 min TN-S TN-C TN-B FP-Te RS R-C RB D Te-S Te-C Te-B Cont | Test #10: 4 hr 45 min TN-S TN-C TN-B FP-TN RS R-C RB D Te-S Te-C Te-B Cont | Test #11: 2 hr 41 min TN-S TN-C TN-B FP-R RS R-C RB Dup Te-S Te-C Te-B Cont | Test #12: 3 hr 8 min TN-S TN-C TN-B FP-Te RS R-C RB D-Te Te-S Te-C Te-B Cont | Test #13: 3 hr 14 min TN-S TN-C TN-B FP-TN RS R-C RB D Te-S Te-C Te-B Cont |
| 1 hr Soak | | | | | Test #14: 3 hr 20 min TN-S TN-C TN-B FP-R RS R-C RB D Te-S Te-C Te-B Cont | Test #15: 3 hr 3 min TN-S TN-C TN-B FP-Te RS R-C RB D-Te Te-S Te-C Te-B Cont | Test #16 A: TN-S TN-C TN-B FP-TN RS R-C RB D Te-S Te-C Te-B Cont | Test #16 B: TN-S TN-C TN-B FP-Te RS R-C RB D Te-S Te-C Te-B Cont | Test #16 C: RS R-C RB FP-R RS R-C RB RS R-C RB |
| 2 hr Soak | | | | | Test #17: 7 hr 43 min TN-S TN-C TN-B FP-Te RS R-C RB D-Te Te-S Te-C Te-B Cont | Test #18: 11 hr 8 min TN-S TN-C TN-B FP-R RS R-C RB Dup Te-S Te-C Te-B Cont | Test #19: 13 hr 42 min TN-S TN-C TN-B FP-Te RS R-C RB D-Te Te-S Te-C Te-B Cont | Test #20: 5 hr 48 min TN-S TN-C TN-B FP-R RS R-C RB Dup Te-S Te-C Te-B Cont | Test #21: 20 hr 47 min TN-S TN-C TN-B FP-TN RS R-C RB D Te-S Te-C Te-B Cont |
| 4 hr Soak | | | | | Test #22: 11 hr 30 min TN-S TN-C TN-B FP-R RS R-C RB D-Te Te-S Te-C Te-B Cont | Test #23: 12 hr 43 min TN-S TN-C TN-B FP-TN RS R-C RB D-Te Te-S Te-C Te-B Cont | Test #24: 12 hr 43 min TN-S TN-C TN-B FP-TN RS R-C RB D-Te Te-S Te-C Te-B Cont | Test #25: 12 hr 43 min TN-S TN-C TN-B FP-TN RS R-C RB D-Te Te-S Te-C Te-B Cont | Test #26: 12 hr 43 min TN-S TN-C TN-B FP-TN RS R-C RB D-Te Te-S Te-C Te-B Cont |
| 6 hr Soak | | | | | Test #27: 12 hr 43 min TN-S TN-C TN-B FP-TN RS R-C RB D-Te Te-S Te-C Te-B Cont | Test #28: 12 hr 43 min TN-S TN-C TN-B FP-TN RS R-C RB D-Te Te-S Te-C Te-B Cont | Test #29: 12 hr 43 min TN-S TN-C TN-B FP-TN RS R-C RB D-Te Te-S Te-C Te-B Cont | Test #30: 12 hr 43 min TN-S TN-C TN-B FP-TN RS R-C RB D-Te Te-S Te-C Te-B Cont | Test #31: 12 hr 43 min TN-S TN-C TN-B FP-TN RS R-C RB D-Te Te-S Te-C Te-B Cont |
| 12 hr Soak | | | | | Test #32: 12 hr 43 min TN-S TN-C TN-B FP-TN RS R-C RB D-Te Te-S Te-C Te-B Cont | Test #33: 12 hr 43 min TN-S TN-C TN-B FP-TN RS R-C RB D-Te Te-S Te-C Te-B Cont | Test #34: 12 hr 43 min TN-S TN-C TN-B FP-TN RS R-C RB D-Te Te-S Te-C Te-B Cont | Test #35: 12 hr 43 min TN-S TN-C TN-B FP-TN RS R-C RB D-Te Te-S Te-C Te-B Cont | Test #36: 12 hr 43 min TN-S TN-C TN-B FP-TN RS R-C RB D-Te Te-S Te-C Te-B Cont |

Keys:

TN-C - Failed

TN-C - Passed

B - Block
 C - Clay
 S - Steel
 TN - TNT
 Te - Teityl
 R - RDX
 FP - Furnace Plates
 D - Duplicated Test Plate and Analysis
 Cont - Contaminated Debris After Treatment

50°F/hr Ramp: Tests 1, 2 & 3
 75°F/hr Ramp: Tests 4, 5, & 6
 100°F/hr Ramp: Tests 7, 8, & 9
 150°F/hr Ramp: Tests 10 & 11
 200°F/hr Ramp: Tests 12 & 13
 300°F/hr Ramp: Tests 14 & 15

TNT (1.4 μ g and 2.2 μ g , respectively), Tests #16A and #16B failed to successfully decontaminate concrete blocks which had been spiked with TNT or Tetryl. Test #16A treated only TNT-contaminated samples. Test #16B treated on Tetryl-contaminated samples. Post-treatment samples of TNT-spiked blocks from Test #16A contained levels as high as 7,962 μ g 2,4,6-TNT and 10,000 μ g of 2,4-DNT. Post-treatment samples of Tetryl-spiked blocks taken after Test#16B contained levels of 1,3,5-TNB from 0.6-191 μ g.. In Tests #16B and #16C (RDX only), some of the furnace test plates, 5 located around the inside perimeter of the furnace walls and door failed to meet treatment criteria.

The failures clearly point to the importance of treatment temperature in decontaminating explosives-contaminated materials. In each test load spiked steel pipe, spiked clay plates and spiked clay blocks were treated. Pre-contaminated debris (metal valving and pipes, chunks of concrete) from the remediation effort were placed with like items in the furnace. For each test run 5 load thermocouples were placed throughout the load to track material temperatures during the test. The average of the five thermocouples was used to define the treatment temperature. When the average thermocouple value, as tracked by the datalogger, was equal to 600°F, the soak time was begun. In the case of a zero soak time, the test run was completed. Figure 2, 3 and 4 provides a comparison of steel, clay and block temperatures respectively at the end of ramp, and soak times for Tests #7, #9, #14, #15, #16A and #16B. Test #7 and #9 were performed with a slow heat ramp-up rate of 100°F per hour. Test #14 and #15 were controlled at a faster heat -up ramp-up rate 300°F. Test 16A and 16B were heat-up as fast as possible within the heat limit of the HGD system. Tests #9, #16A and #16B were conducted at 600°F and zero soak time. Tests #7, #14 and #15 were conducted at 600°F and 1-hour soak time.

For steel, Figure 2 shows that at a temperature of 565°F, which can be reached as little as 1 hours and as long as 5 hours and 15 minutes, can effectively treat concrete surface contamination. For clay, Figure 3 shows that at a average temperature of 571°F, which can be reached as little as 1 hour 5 minutes and as long as 4 hours 35 minutes, can effectively treat explosives-contaminated clay material.

For concrete, Figure 4 show that the material must reach 513°F between 2 hours and 5 hours. Test #16A and 16B failed because the surface temperature never reached above the 513°F before the tests was stopped. However, if the test were continued at the same heat-up rate, the material could have reached the treatment temperature in less than 1 hour and 34 minutes.

From the graphs presented in Figure 2, 3, and 4 one fact becomes clear: material temperatures between the ranges of 513-565°F is required to successfully decontaminate explosives-contaminated material. Materials which do not reach this temperature range (i.e., block samples from Tests#16A and #16B) are not completely decontaminated. Soak times and ramp-up times are of little importance as long as material temperatures reach the minimum required treatment temperature. However, to reduced the total processing time, a faster heat-up rate is preferred. The HGD process can heat up concrete up to the treatment temperature range in less than 2 hours. The graph also indicates the advantages in processing loads of similar materials so that the temperature differential problems (i.e., between steel and block) could be avoided.

Throughout testing, regardless of test conditions, TNT proved the most difficult explosives compound to decontaminate and RDX the easiest compound. Test #2 was conducted at 300°F in order to achieve define a temperature which **did not** successfully treat RDX. Non-porous materials (steel) were easier to decontaminate than more porous materials such as clay or concrete, however once materials treatment temperatures of at least 513°F decontamination was achieved.

Figure 2: STEEL MATERIAL TEMPERATURE

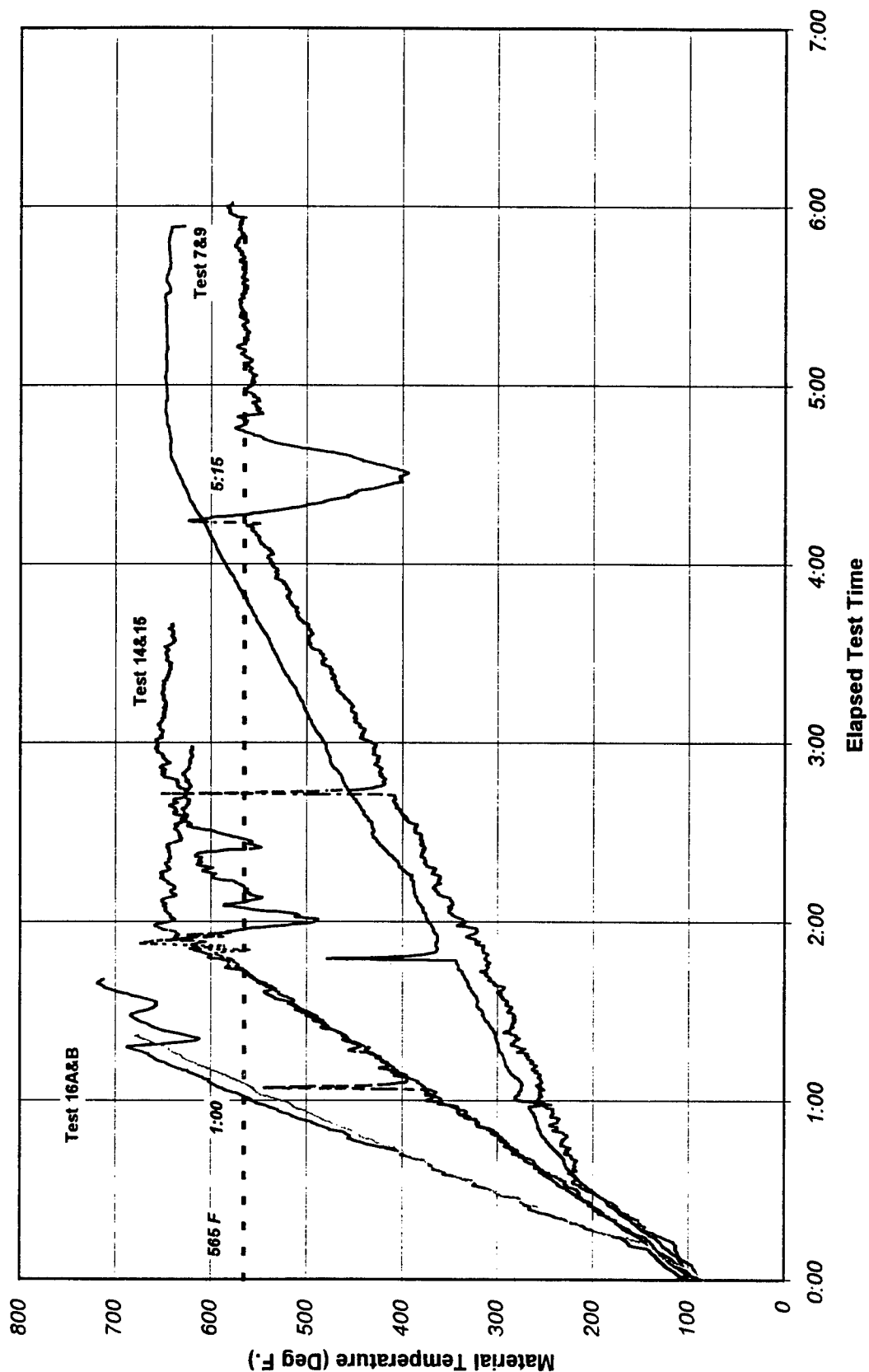


Figure 3: CLAY MATERIAL TEMPERATURE

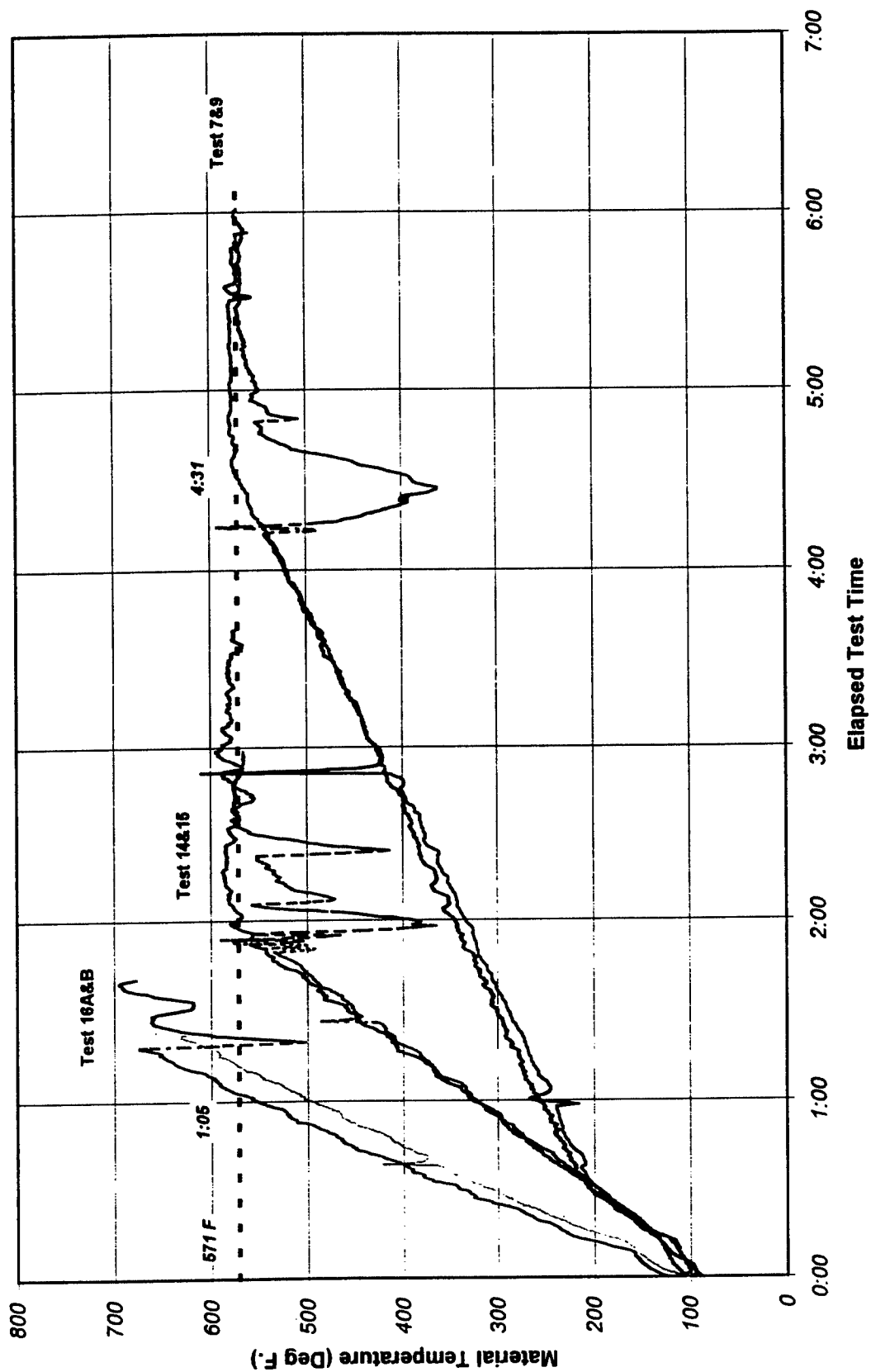
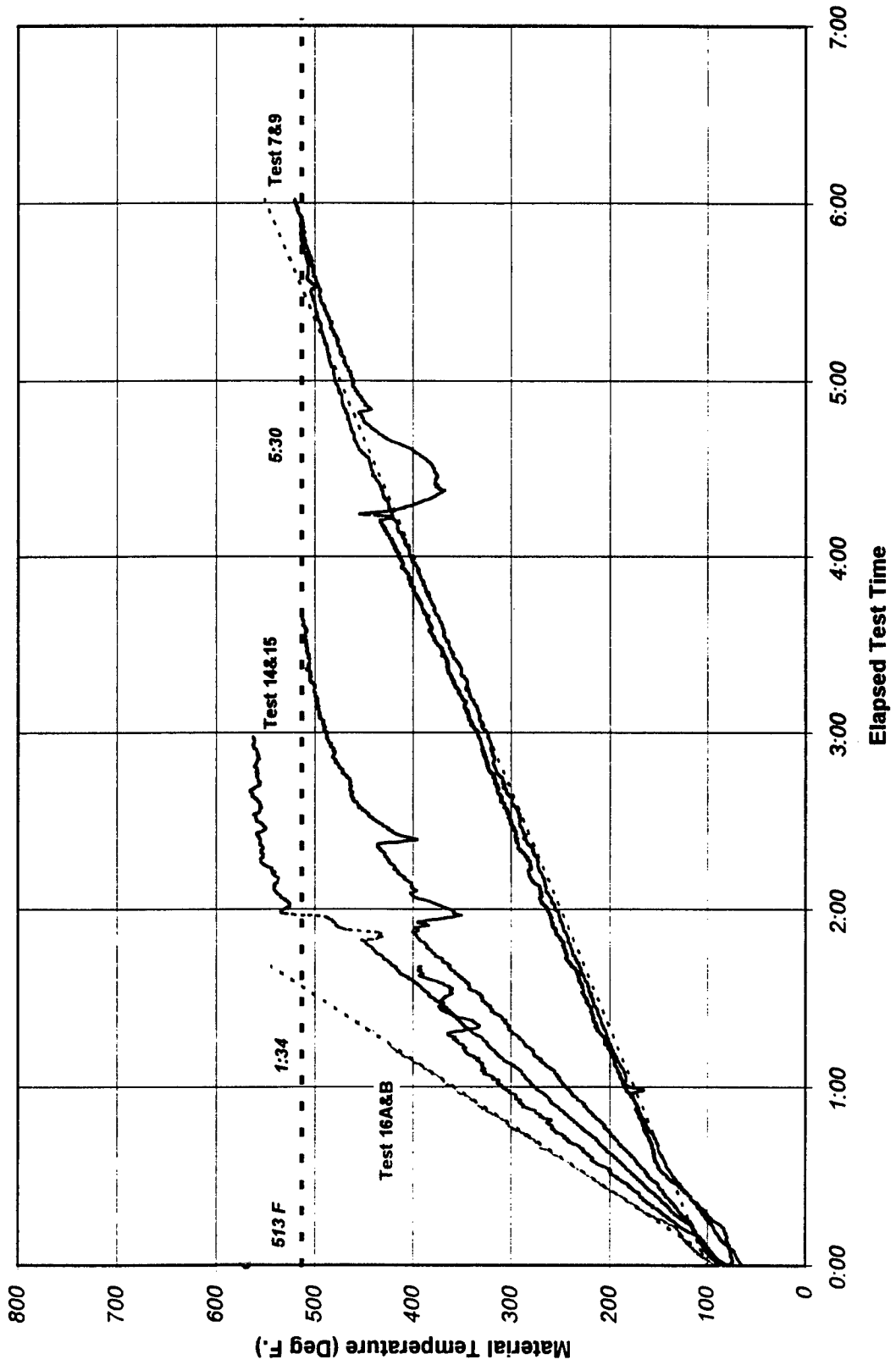


Figure 4: CONCRETE MATERIAL TEMPERATURE



A review of post-treatment sampling results indicates that many of the residual contamination levels are low; but are they low enough to pass standard accepted treatment criteria for explosives? In order to provide a comparison of the residual contamination levels found to an accepted treatment criteria, WESTON converted the residual levels of contaminants (μg) found on the post-treatment wipe and ground samples concentration ($\mu\text{g/g}$ for ground samples and $\mu\text{g/sq. in}$ for wipe samples). The resultant concentrations were graphed against pre-treatment concentration of spike explosives and compared against a 99.99% removal requirement. In the case of the ground samples the final concentration was also compared against a 1 ppm treatment criteria for explosives which WESTON is currently required by ADEM to meet prior to backfilling explosives-contaminated soils which have been incinerated. Figure 5 illustrates that all wipe samples, except for those taken following test (12 which was conducted at 300°F) were able to successfully pass the 99.99% removal criteria. Figure 6 indicates that all but one of the ground samples which passed the 99.99% removal criteria was able to pass the 2ppm backfill criteria. Those ground samples which did not meet the 99.99% removal criteria had not reached temperatures sufficiently hot enough to completely decontaminate the spike explosives.

Discussion of Level 2 Results:

Table 3 provides a test matrix indicating the results of validation tests meeting the acceptance criteria defined by Level 2. Dark, shaded blocks on Table 3 indicate post-treatment samples which still indicate some level of the original spike explosive. Failures noted on this table may have passed the 99.99% removal criteria, but still contain traces of the original spike explosives. Contaminated debris from the ALAAP remediation area were not considered in this acceptance level, because initial contamination levels were unknown.

Using Level 2 acceptance criteria, the data included on Table 3 indicates that the spike explosives were successfully decontaminated (no trace of the original spike explosives or breakdown compounds) at treatment temperatures of 600°F (Tests #5, #6, #7, #9, #14, #15, #16B, and #16C) regardless of soak time. Test #16A failed to meet level 2 criteria due to the inability to treat concrete block spiked with TNT. Sample blocks were spiked with quantities between 9.4 - 11.6 grams of TNT. Although the removal efficiencies for these samples were in the 99.92% range, the residual TNT levels after treatment were between 6,302 - 10,000 μg .

Because the treatment temperature was based on an average of 5 material thermocouples distributed throughout the load, it's suspected that the spiked test block did not reach a temperature which was high enough to completely vaporize the TNT on the test block. The system data logger indicated the highest surface temperature reached by the concrete blocks contained in the furnace load to be 394°F whereas the metal pipe in the load reached a treatment temperature as between 565-710°F.

Table 3 also indicates that spike explosives were successfully decontaminated (no trace of the original spike explosives or breakdown compounds) at treatment temperatures of 500°F (Tests #1, #3, #4, and #8) provided the soak time was greater than or equal to 2-hours. Test #13, which was conducted at 500°F and a 1-hour soak, failed the level 2 criteria because of a 66 μg hit of TNT found in the TNT ash residual left behind on a spiked furnace test plate located in the rear of the furnace. As noted earlier, TNT was the most difficult explosive to treat, but at treatment temperatures below 600°F TNT usually left an ash residual behind. The ash residual had a shiny, glass-like appearance. It was very light in weight and in most cases formed a "soufflé" on the test plates. In all cases the residual was sampled, by grinding the ash and then sampling the ground ash in accordance with Method 8330.

**Figure 5: POST TREATMENT EXPLOSIVES RESIDUAL
ANALYSIS (WIPESAMPLES)**

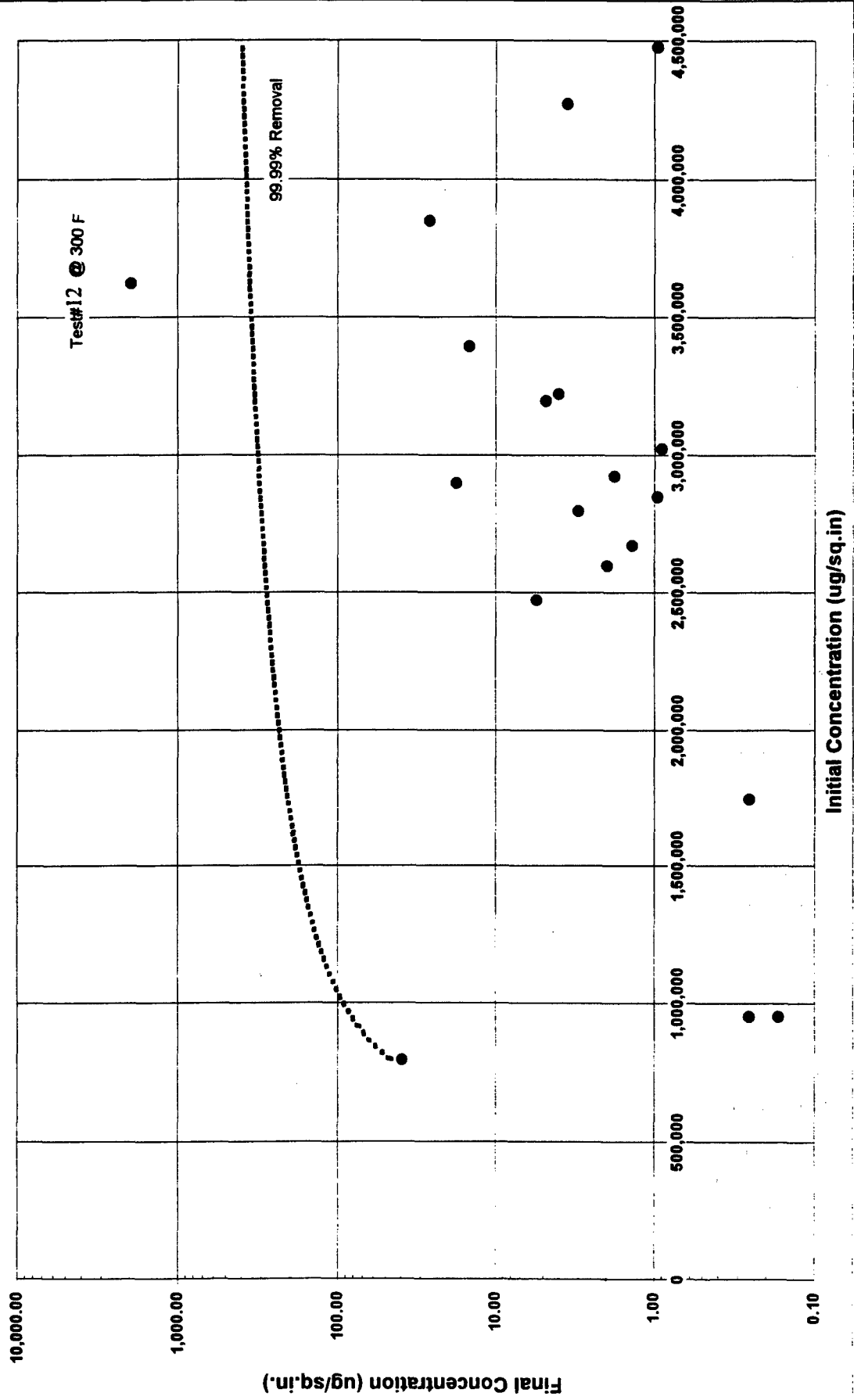


Figure 6: POST TREATMENT EXPLOSIVES RESIDUAL
ANALYSIS (SOLID SAMPLES)

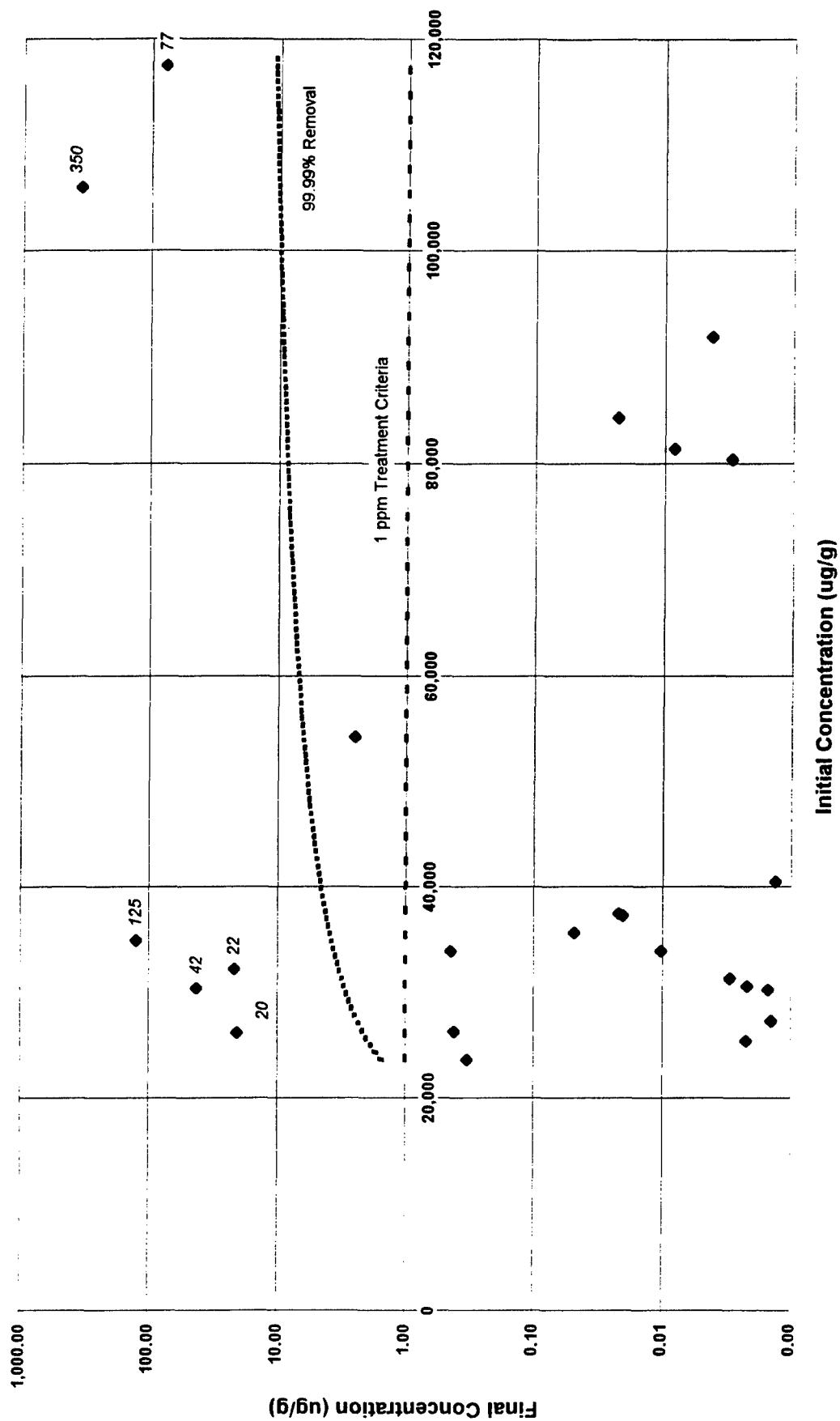


Table 3: LEVEL 2 ACCEPTANCE CRITERIA

| | 300°F | 400°F | 500°F | 550°F | 600°F | 600°F | 600°F | 600°F | 600°F |
|------------|-----------------------------------------------------------------------------------|------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|--------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|------------------------------------------------------------------------------------|--------------------------------------------------------------------------|--------------------------------------------------------------------------|
| No Soak | | | | | | | | | |
| 1 hr Soak | Test #12: 3hr 8 min TN-S TN-C TN-B FP-Te R-S R-C R-B D-Te Te-S Te-C Te-B | Test #11: 2 hr 41 min TN-S TN-C TN-B FP-R R-S R-C R-B D-Te Te-S Te-C Te-B | Test #13: 3 hr 14 min TN-S TN-C TN-B FP-TN R-S R-C R-B D-Te Te-S Te-C Te-B | Test #10: 4 hr 46 min TN-S TN-C TN-B FP-TN R-S R-C R-B D-Te Te-S Te-C Te-B | Test #9: 6hr 16 min TN-S TN-C TN-B FP-Te R-S R-C R-B D Te-S Te-C Te-B | Test #14: 3 hr 20 min TN-S TN-C TN-B FP-TN R-S R-C R-B D-Te Te-S Te-C Te-B | Test #15: 3 hr 3 min TN-S TN-C TN-B FP-Te R-S R-C R-B D-Te Te-S Te-C Te-B | Test #16 C TN-S TN-C TN-B FP-Te R-S R-C R-B D-Te Te-S Te-C Te-B | Test #16 C TN-S TN-C TN-B FP-Te R-S R-C R-B D-Te Te-S Te-C Te-B |
| 2 hr Soak | | | | | | | | | |
| 4 hr Soak | | | | | | | | | |
| 6 hr Soak | | | | | | | | | |
| 12 hr Soak | | | | | | | | | |

KEYS:

B-Block
C-Clay
S-Steel

TNC-Failed

TNC-Passed

TN - TNT
Te- Tetra
R - RDX
FP - Furnace Plates
D - Duplicated Test Plate and Analysis
Cont - Contaminated Debris After Treatment

50°F/hr Ramp: Tests 1, 2 & 3
75°F/hr Ramp: Tests 4, 5, & 6
100°F/hr Ramp: Tests 7, 8, & 9
150°F/hr Ramp: Tests 10 & 11
200°F/hr Ramp: Tests 12 & 13
300°F/hr Ramp: Tests 14 & 15

Discussion of Level 1 Results

Table 4 provides a test matrix indicating the results of the validation tests using Level 1 acceptance criteria. Level 1 was the easiest acceptance criteria to meet. Dark, shaded squares indicate failures or post-treatment samples which contained explosives residuals levels in excess of 99.9999% removal. Contaminated debris from the ALAAP remediation area were not considered for this acceptance level, because initial contamination levels were unknown.

In general Level 1 results mirror the test data presented in Table 3: spike explosives were successfully decontaminated ($\geq 99.9999\%$ removal) at treatment temperatures between 550°F and 600°F (Tests #5, #6, #7, #10, #14, and #15,) and a soak time of at least 1 hour. Although tests conducted at 500°F (Tests #13 and #8) pass the 99.9999% removal criteria, and successfully decontaminated the spike explosives, some explosives- breakdown compounds still remain as indicated on Table 2 which evaluated the same data to Level 3 criteria.

HGD Emissions Results

Stack monitoring was conducted to provide an indicator of total system performance, and to provide "real" data to support future permitting efforts. Sampling trains were located at the interconnecting duct between the furnace exit and afterburner entrance, and at the stack discharge to determine the DRE of the hot-gas decontamination process. Sampling was conducted for Test #1, #2 and #3. Since the amount of emissions data generated during the validation tests is immense, a tabulation of the testing results will be presented. Each of the tables presenting stack data indicate "hits" only.

Explosives emissions at the system stack were sampled using EPA Method 0010. The results, presented in Table 5, indicate no detectable explosives-contamination were observed in the stack emission of the hot-gas system. Explosives samples taken at the interconnection duct indicate that explosives-contamination in the furnace is vaporized, and drawn through the duct prior to destruction in the system afterburner. During Test #1 a mid-soak explosives sample was also taken. This sample was taken between hours 4.5 and 7, and corresponded to the middle of the 12-hour soak period associated with Test #1. Based on previous tests, it was suspected that the majority of decontamination occurs during the heat-up and early stages of the soak period. The purpose of mid-soak sample was to verify that suspicion. As indicated by Table 6, no explosives were detected in the mid-soak sample, thereby confirming that little or no decontamination occurs 4-hours into the soak period. The overall destruction and removal efficiencies for the overall hot-gas system and afterburner system are indicated on Table 7.

Particulate, Chlorine gas (Cl_2), and hydrochloric acid (HCl) emissions were sampled using EPA Method 0050. The filterable particulate analysis was performed using Method 5; Method 9057 (ion chromatography) was used to determine HCl and Cl_2 levels. The results are presented in Table 6. The regulatory criteria for particulate emissions is < 0.08 grains per dry standard cubic feet (gr./dscf) corrected to 7% O_2 . Particulate results from the validation tests #1-#3 were well below the regulatory criteria and ranged from 0.000222 to 0.000656 $\text{gr./dscf @ 7\% O}_2$. HCl emissions for Tests #1, #2, and #3 were 0.00177, 0.0015 and 0.0014 lbs/hr , respectively which are well below the regulatory limit of 4 lbs/hr . Emissions limits for chlorine gas do not exist unless defined by a tier analysis, however chlorine gas emissions for all Tests #1-#3 were 2.06×10^{-4} , 0.00105 and 0.00108 lbs/hr . Metals stack emissions were sampled for the following metals in accordance with draft EPA Method 29: antimony, arsenic, barium, beryllium, cadmium, chromium, lead, mercury, nickel, selenium, silver, thallium and hexavalent chromium. Hexavalent chromium was sampled in accordance with EPA CR⁺⁶ Method..

Table 4: LEVEL 1 ACCEPTANCE CRITERIA

| | 300°F | 400°F | 500°F | 550°F | 600°F | 600°F | 600°F | 600°F |
|------------|---------------------------------------------------------------------------------|----------------------------------------------------------------------------------|----------------------------------------------------------------------------------|----------------------------------------------------------------------------------|---------------------------------------------------------------------------------|----------------------------------------------------------------------------------|---------------------------------------------------------------------------------|---------------------------------------------------------------------------------|
| No Soak | | | | | | | | |
| 1 hr Soak | Test #12: 3 hr 8 min TN-S TN-C TN-B FP-Te R-S R-C R-B D Te-S Te-C Te-B | Test #11: 2 hr 41 min TN-S TN-C TN-B FP-Te R-S R-C R-B D Te-S Te-C Te-B | Test #13: 3 hr 14 min TN-S TN-C TN-B FP-Te R-S R-C R-B D Te-S Te-C Te-B | Test #10: 4 hr 46 min TN-S TN-C TN-B FP-Te R-S R-C R-B D Te-S Te-C Te-B | Test #9: 6 hr 15 min TN-S TN-C TN-B FP-Te R-S R-C R-B D Te-S Te-C Te-B | Test #14: 3 hr 20 min TN-S TN-C TN-B FP-Te R-S R-C R-B D Te-S Te-C Te-B | Test #15: 3 hr 3 min TN-S TN-C TN-B FP-Te R-S R-C R-B D Te-S Te-C Te-B | Test #16: 3 hr 3 min TN-S TN-C TN-B FP-Te R-S R-C R-B D Te-S Te-C Te-B |
| 2 hr Soak | | | | | | | | |
| 4 hr Soak | | | | | | | | |
| 6 hr Soak | | | | | | | | |
| 12 hr Soak | | | | | | | | |

Keys:

B- Block
C- Clay
S- Steel

TN-C
Failed

TN-C
Passed

TN - TNT
Te - Tetra
R - RDX
FP - Furnace Plates
D - Duplicated Test Plate and Analysis
Cont - Contaminated Debris After Treatment

50°F/hr Ramp: Tests 1, 2 & 3
75°F/hr Ramp: Tests 4, 5, & 6
100°F/hr Ramp: Tests 7, 8, & 9
150°F/hr Ramp: Tests 10 & 11
200°F/hr Ramp: Tests 12 & 13
300°F/hr Ramp: Tests 14 & 15

Table 5: SUMMARY OF EXPLOSIVE COMPOUNDS

| | At Furnace Discharge | | | At Afterburner Discharge | | |
|------------------------------|----------------------|-------------------------|-------------|--------------------------|-------------|-------------|
| | Test Run #1 | Test Run #1 Mid-Soak | Test Run #2 | Test Run #3 | Test Run #1 | Test Run #2 |
| Date: | 31-Jan-96 | | 2-Feb-96 | 4-Feb-96 | 31-Jan-96 | 2-Feb-96 |
| Time: | 1832-0122 | | 1405-2100 | 1406-2106 | 1834-0110 | 1406-2031 |
| Explosives Emissions: ppb/v | | | | | | |
| HMx | ND | ND | ND | ND | ND | ND |
| RDX | 24.23 | 0.06 | 54.30 | 23.20 | ND | ND |
| Trinitrobenzene (1,3,5-TNB) | 11.49 | 0.30 | 11.38 | 9.98 | ND | ND |
| Dinitrobenzene (1,3-DNB) | 0.24 | ND | 0.23 | 0.60 | ND | ND |
| Nitrobenzene (NB) | ND | ND | ND | ND | ND | ND |
| Tetryl | 3.16 | ND | 2.99 | 1.90 | ND | ND |
| 2,4,6-Trinitrotoluene (TNT) | 707.18 | 5.33 | 192.26 | 193.24 | ND | ND |
| 2,6-Dinitrotoluene (2,6-DNT) | ND | ND | 0.48 | ND | ND | ND |
| 2,4-Dinitrotoluene (2,4-DNT) | 1.20 | ND | ND | ND | ND | ND |

ND - Analyte detected at less than the detection limit value

Midsoak - This sample was taken between hours 4-7 of the 12 hour soak period of Test Run #1

Table 6: OVERALL HOT GAS SYSTEM REMOVAL EFFICIENCY

| Explosive Removal Efficiency (%) | Overall Hot Gas System Removal Efficiency ⁽¹⁾ | | | Afterburner Removal Efficiency ⁽²⁾ | | |
|----------------------------------|----------------------------------------------------------|-------------------------|-------------------------|-----------------------------------------------|-------------------------------------|-------------------------------------|
| | Test Run #1 31 Jan 96 | Test Run #2 2 Feb 96 | Test Run #3 4 Feb 96 | Test Run 1 31 Jan 96 1832-0122 | Test Run 2 2 Feb 96 1405-2100 | Test Run 3 4 Feb 96 1406-2036 |
| 2,4,6 - Trinitrotoluene (TNT) | > 99.997 | > 99.95 | > 99.94 | > 99.97 | > 99.86 | > 99.86 |
| Tetryl | > 99.79 | > 99.92 | > 99.94 | > 84.91 | > 79.09 | > 67.15 |
| RDX | > 99.88 | > 99.97 | > 99.91 | > 98.30 | > 99.00 | > 97.68 |

⁽¹⁾ Based on total explosives introduced to furnace converted to lb/hr (using total test times) and afterburner discharge mass rate determination for each explosive.

⁽²⁾ Afterburner removal efficiency based on the following: $\% RE = \frac{AFT\ IN - AFT\ OUT}{AFT\ IN} \times 100$

NOTES: All removal efficiencies reported as greater than since no explosives were measured above the method detection limit at the afterburner discharge.

lbs/hr, respectively for Tests #1-#3. Mercury emissions levels were less than 1.37×10^{-7} lbs/hr. Hexavalent chromium emissions were, as expected, negligible (refer to Table 5). The metals and hexavalent chromium results are provided in Table 7. Allowable emissions limits for these metals are normally established using a tier analysis and modeling, however, total metals emissions, not including hexavalent chromium and mercury, were calculated to be $< 9.74 \times 10^{-5}$ lbs/hr, $< 6.04 \times 10^{-5}$ lbs/hr, and 3.65×10^{-5} lbs/hr, respectively for tests #1 - #3. Total carcinogenic metals (Arsenic, Beryllium, Cadmium, and Chromium) emissions were calculated to be $< 5.19 \times 10^{-5}$ lbs/hr, $< 5.09 \times 10^{-5}$ lbs/hr, and 3.95×10^{-5} lbs/hr.

Volatile and semi-volatile compounds found in the stack emissions are presented in Tables 8. These tables identify both products of incomplete combustion and breakdown components as a result of treating explosives. High levels of acetone (0.145, 0.0798, and 0.0399 ppm/volume) were found in the volatile organics analysis and occur as a result of using acetone to make the explosives-spike mixtures. Semi-volatile samples were analyzed for TCL semi-volatile target compounds. Only non-target compounds were identified. The -thalate compounds identified are due to lab solvents used in the sample extraction process.

Dioxin and furan data is reported in Table 9. The total detected 2,3,7,8-TCDD Equivalents for tests #1, #2, and #3 were 0.0395, 0.0221, and 0.0309 ng/dscm which are well below the 30 total ng/dscm suggested by the existing guidelines.

The results from the stack continuous emissions monitoring (CEM) system indicate that total hydrocarbons (THC), sulfur dioxide (SO₂), Nitrous Oxides (NO_x), Carbon monoxide (CO), and Carbon Dioxide (CO₂) were significantly below the allowable limits usually associated with permitting. Since testing was conducted under the rules of a treatability study, meeting a permitted limit was not required, however, in actual applications it would be expected that standard accepted regulatory limits defining CO, CO₂, THC and NO_x would apply.

Of particular interest during all the validation tests was the NO_x data. NO_x was measured at both the interconnecting duct and the stack. During ramp-up periods for each test run, the CEM data indicated increased NO_x activity well above the baseline level of non-detected, until the average load temperature (as measured by 5 thermocouples placed throughout the load) reached approximately 400°F. This seemed to be an indication that the bulk of decontamination activity was complete. Shortly after reaching 400°F, the NO_x analyzers would return to baseline non-detected levels.

CONCLUSIONS

The Hot Gas Decontamination (HGD) Demonstration Program at ALAAP demonstrated the solidness of the equipment design, and efficacy, safety, and economics of the HGD process to remove and destroy explosives residues such as TNT, RDX, and Tetryl from metal, clay, and concrete piping and debris.

Using the most stringent acceptance criteria, an average load temperature of 600°F with a 1-hour soak time is sufficient to decontaminate a 3,000 LB load of piping and debris which has been contaminated with quantities of TNT, RDX and Tetryl which total no more than 1 LB explosives.

Test results indicated that TNT was the hardest explosive to completely decontaminate (600°F, 1 hour soak), while RDX was the easiest (400°F, soak). In addition to the recommended optimum treatment conditions, test results also indicate that the HGD process was able to effectively decontaminate

Table 7: METALS, HCL, CL₂ AND PARTICULATE EMISSION RESULTS

| Metals Emissions Rate lbs/hr | Date: | Test Run #1 | Test Run #2 | Test Run #3 |
|------------------------------------------|-------|-------------|-------------|-------------|
| | Time: | 31-Jan-96 | 2-Feb-96 | 4-Feb-96 |
| | | 1834-0103 | 1406-2011 | 1415-2026 |
| Antimony | | 4.11E-06 | 9.54E-07 | <1.11E-05 |
| Arsenic | | <7.50E-06 | <7.38E-06 | <7.46E-06 |
| Barium | | 2.16E-05 | 2.78E-07 | 2.16E-07 |
| Beryllium | | 1.96E-08 | <2.40E-08 | <2.45E-08 |
| Cadmium | | 1.57E-06 | 7.57E-07 | <6.87E-07 |
| Chromium | | 4.28E-05 | 4.27E-05 | 3.13E-05 |
| Lead | | 1.70E-05 | 3.55E-06 | 2.45E-06 |
| Mercury | | 1.37E-07 | 2.35E-07 | 2.95E-08 |
| Nickel | | 1.03E-05 | 1.22E-05 | 2.55E-06 |
| Selenium | | <8.68E-06 | <8.53E-06 | <8.64E-06 |
| Silver | | <2.20E-06 | <2.16E-06 | <2.20E-06 |
| Thallium | | <7.65E-06 | <7.48E-06 | <7.66E-06 |
| Hexavalent Chromium ** | | 5.10E-05 | 5.29E-05 | 3.85E-05 |
| HCL, ppm/v | | 0.31 | 0.27 | 0.27 |
| Cl ₂ , ppm/v | | 0.019 | 0.098 | 0.109 |
| Particulate, gr/dscf @ 7% O ₂ | | 4.52E-04 | 2.22E-04 | 6.56E-04 |

< Indicates the analyte was detected at values less than the detection limit indicated

** The hexavalent chromium values reported may not be truly representative.

The hexavalent chromium values exceed the total chromium values obtained using the multi-metals test train.

The hexavalent chromium test train has not been validated by EPA for use on sources > 300°F

Table 8: VOLATILE AND SEMI-VOLATILE ORGANIC COMPOUNDS

| Average** VOST Emissions, ppm/v | Date: | Test Run #1 | Test Run #2 | Test Run #3 | Average VOST Emissions |
|------------------------------------|-------|------------------------|-----------------------|-----------------------|------------------------------|
| | Time: | 31-Jan-96 1846-2322 | 2-Feb-96 1419-2005 | 4-Feb-96 1418-1950 | |
| Chloromethane (Methyl Chloride) | | 6.78E-02 | 1.59E-02 | 3.03E-02 | 3.80E-02 |
| Bromomethane (Methyl Bromide) | | 3.18E-03 | 1.22E-03 | 2.04E-03 | 2.15E-03 |
| Methylene Chloride | | 9.84E-04 | 9.55E-04 | 1.19E-03 | 1.04E-03 |
| Acetone | | 1.45E-01 | 7.98E-02 | 3.99E-02 | 8.82E-02 |
| Carbon Disulfide | | < | 3.18E-04 | 2.10E-04 | 1.76E-04 |
| Chloroform | | 1.82E-04 | 1.80E-04 | 1.14E-04 | 1.59E-04 |
| Benzene | | 9.70E-04 | 2.72E-04 | 3.78E-04 | 5.40E-04 |
| Toluene | | 4.72E-04 | 1.07E-04 | 1.22E-04 | 2.34E-04 |
| Styrene | | 1.14E-04 | 4.37E-04 | 4.28E-04 | 3.26E-04 |
| Xylenes (total) | | 2.76E-04 | 2.85E-04 | 2.01E-04 | 2.54E-04 |

| Semivolatile Emissions: ppb/v | Test Run #1 | Test Run #2 | Test Run #3 |
|----------------------------------|-------------|-------------|-------------|
| Diethylphthalate | 0.168 J | 0.73 J | ND |
| Pentachlorophenol | 0.05 J | 0.25 J | ND |
| Di-n-butylphthalate | 0.08 J | ND | ND |
| Benzo(a)anthracene | ND | 0.06 J | ND |
| Chrysene | ND | 0.04 J | ND |
| bis(2-Ethylhexyl)phthalate | 0.28 JB | 0.13 JB | 0.15 JB |
| Di-n-octylphthalate | ND | 0.02 J | ND |

< Indicates value less than detection limits

** Detection Limit Values are included in the overall average

J = Detected in samples in quantities less than the detection limits

B = Detected in field blank in quantities greater than the samples, therefore the sample values are not blank corrected

Table 9: DIOXIN AND FURAN EMISSION RESULTS

| Date: Time: | Test Run #1 31-Jan-96 1834-0121 | Test Run #2 2-Feb-96 1405-2038 | Test Run #3 4-Feb-96 1410-2045 |
|-----------------------------------------------------------------|------------------------------------------------------------|-----------------------------------------------------------|-----------------------------------------------------------|
| Detected Toxicity Equivalency Emissions, ng/dscm | | | |
| 2,3,7,8-TCDD | 7.82E-03 | 4.09E-03 | 4.39E-03 |
| 1,2,3,7,8-PeCDD | 1.56E-02 | 7.17E-03 | 1.21E-02 |
| 1,2,3,4,7,8-HxCDD | 2.54E-03 | 1.23E-03 | 1.32E-03 |
| 1,2,3,6,7,8-HxCDD | 2.93E-03 | 1.02E-03 | 1.54E-03 |
| 1,2,3,7,8,9-HxCDD | 6.45E-03 | 2.25E-03 | 3.95E-03 |
| 1,2,3,4,6,7,8-HpCDD | 2.35E-03 | 6.96E-04 | 1.60E-03 |
| OCDD | 6.06E-04 | 2.25E-04 | 4.39E-04 |
| 2,3,7,8-TCDF | ND | 2.05E-04 | 2.20E-04 |
| 1,2,3,7,8-PeCDF | ND | 1.02E-04 | 2.20E-04 |
| 2,3,4,7,8-PeCDF | ND | 3.07E-03 | 2.20E-03 |
| 1,2,3,4,7,8-HxCDF | 3.91E-04 | 8.19E-04 | 1.32E-03 |
| 1,2,3,6,7,8-HxCDF | 1.96E-04 | 4.09E-04 | 6.59E-04 |
| 2,3,4,6,7,8-HxCDF | 3.91E-04 | 6.14E-04 | 6.59E-04 |
| 1,2,3,7,8,9-HxCDF | ND | ND | ND |
| 1,2,3,4,6,7,8-HpCDF | 9.78E-05 | 1.64E-04 | 2.20E-04 |
| 1,2,3,4,7,8,9-HpCDF | 1.96E-05 | 2.05E-05 | 4.39E-05 |
| OCDF | 1.56E-05 | 1.02E-05 | 1.10E-05 |
| Detected Total 2,3,7,8-TCDD Equivalents, ng/dscm | 0.0395 | 0.0221 | 0.0309 |

Calculated Total 2,3,7,8-TCDD equivalents based on detected values only

explosives-contaminated debris to microgram quantities while achieving at least 99.99 % destruction and removal efficiency at a full range of additional treatment temperatures and soak times.

For any group interested in using this process, we recommend a pilot run to verify the optimum treatment temperatures and times for your special loading conditions and contaminants. A pilot run will also allow the user to verify the presence or lack of breakdown compounds which could affect acceptance criteria.

In summary, based on WESTON's experience using the transportable hot-gas decontamination equipment at the ALAAP for the decontamination of explosives-contaminated piping and debris, a number of potential advantages as well as a few disadvantages were identified.

Assuming 5X decontamination is the goal, the hot-gas process has the following advantages over open burning/open detonation and/or using a flash furnace:

- Safer operation and reduced health risk to operators
- The ability to 5X decontaminate complicated machinery without destroying the structural integrity of the machinery
- The process can be designed to meet or exceed mandated air quality emissions
- Night or day operation, which is not generally affected by the weather conditions
- Treated materials could be reused instead of scrapped or landfilled
- The hot-gas process is a proven and easily available technology
- The system is easy to operate and can be operated with as few as two persons
- Process equipment can be either permanent or transportable to suit operations needs

Assuming 5X decontamination, the hot-gas process has the following disadvantages when compared to open burning/open detonation and/or using a flash furnace:

- The initial cost of capital equipment and the ongoing cost associated with operating the equipment
- Materials should be decontaminated to meet 3X conditions prior to processing
- Further testing is required to verify the effectiveness of the hot-gas process on energetic
- The 5X definition (materials heated to at least 1,000°F for at least 15 minutes) needs to be revised to include the Hot-Gas process